Fermilab

"Bo" LArTPC Cryostat
Piping System Engineering Note

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Date: ________________________________

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1.0 Introduction

This document constitutes the Piping System Engineering Note for the cryogenic piping associated with the LArTPC cryostat known as "Bo" which is located inside the Proton Assembly Building at Fermilab.

The cryogenic piping transports liquid argon to the cryostat for the purpose of filling the cryostat with ultra-pure liquid argon. The pipe descriptions and a summary of the operating parameters are shown in Table 1.1.

Table 1.1: Cryogenic piping description and summary

Description	Fluid	OD (in)	ID (in)	P oper (psid)	P max (psid)	Temp (approx)
"Bo" LAr supply line (vacuum jacketed)	GAr/LAr	0.500	0.430	250	400	87 K
"Bo" relief valve supply piping	GAr/LAr	1.90	1.682	10	35	87 K
"Bo" relief valve discharge vent piping	GAr/LAr	3.00	2.87	0	< 1	87 K
"Bo" cooldown/blowdown vent piping	GAr/LAr	0.500	0.430	< 15	<< 350	87 K

2.0 Flow schematic

The relevant portion of the flow schematic for the cryostat is shown in Figure 2.1. The complete flow schematic is available at http://lartpc-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=265 in Section 1.2.

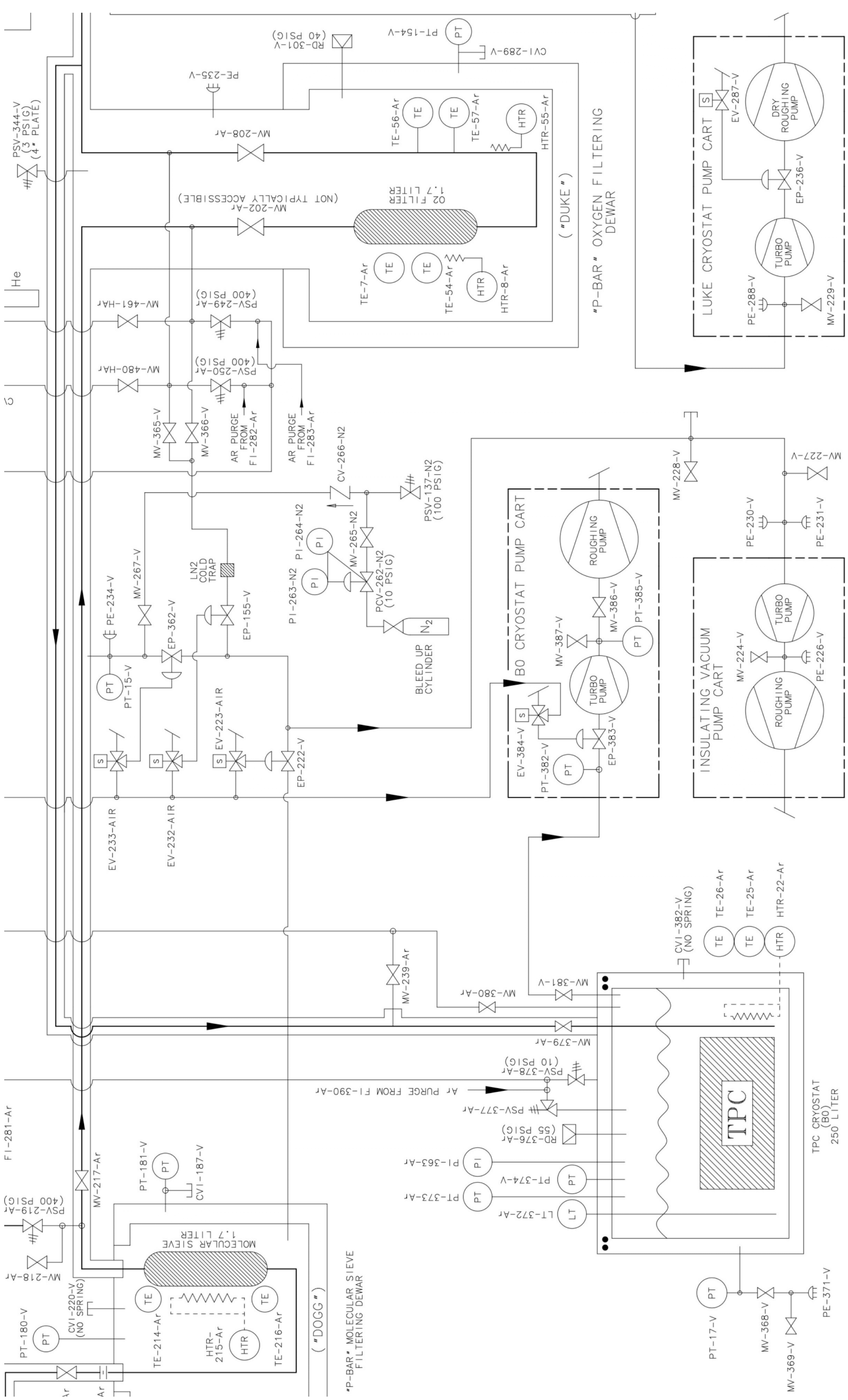


Figure 2.1 Cryostat piping flow schematic.

3.0 Design codes and evaluation criteria

The "Bo" LArTPC cryostat piping must meet all of the requirements of Section 5031.1 of the Fermilab ES&H Manual. This section states that piping systems containing cryogenic fluids fall under the category of Normal Fluid Service and shall adhere to the requirements of the ASME Process Piping Code B31.3.

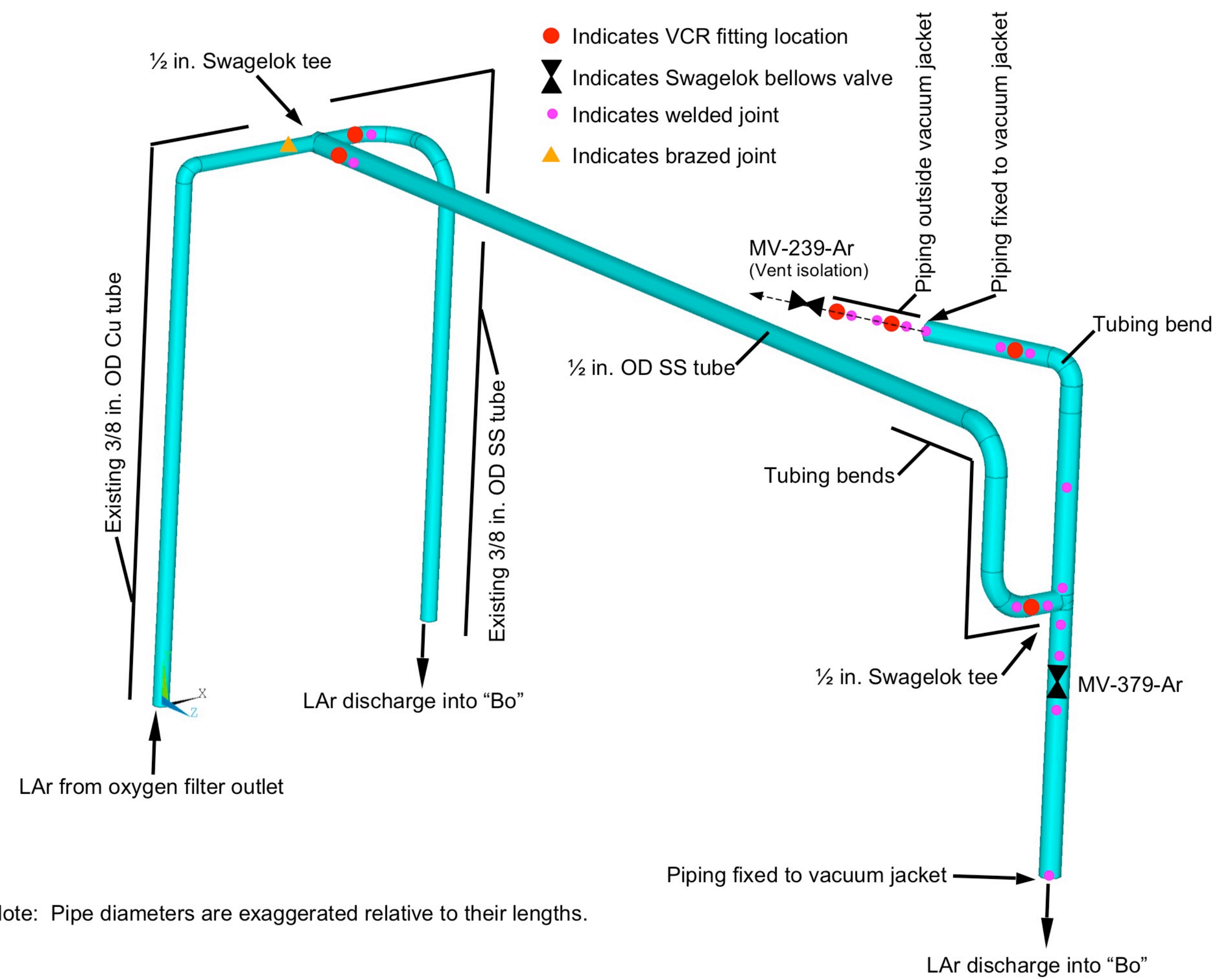
4.0 Materials

The piping is fabricated from 304/304L stainless steel tube and pipe. In addition to 304/304L material, some of the components and flanges are 316/316L stainless steel. The lowest allowable stress for both of these materials from Table A-1 of ASME B31.3 will be used in this analysis, which is 16,700 psi. A portion of the existing piping that feeds the new construction is fabricated from copper tube for which Table A-1 lists 6,000 psi as the allowable stress.

The LAr piping will be operated at 87 K. This is above the minimum temperature listed for 304/316 stainless steel pipe or tube (19 K). According to Table 323.2.2 of the Code, impact testing is not required for these austenitic stainless steels. However, Table 323.2.2 does require impact testing of the weld metal and heat affected zone except as stated in Table 323.2.2 Note (6) where impact testing is not required when the minimum obtainable Charpy specimen has a width along the notch of less than 2.5 mm (0.098 in). All of the pipe or tube used in the "Bo" cryostat piping system has a manufacturer's minimum wall thickness less than 0.098 in. Therefore, impact testing is not required for this piping system. It should also be noted the Fermilab has extensive service experience using the 300 series stainless steels at liquid nitrogen temperatures.

5.0 Piping design and analysis

A schematic of the piping that supplies LAr to "Bo" is shown in Figure 5.1. The cooldown/bypass vent piping associated with "Bo" is shown in Figure 5.2.



Note: Pipe diameters are exaggerated relative to their lengths.

Figure 5.1: "Bo" LAr supply line.

Note: Pipe diameters are exaggerated relative their lengths.

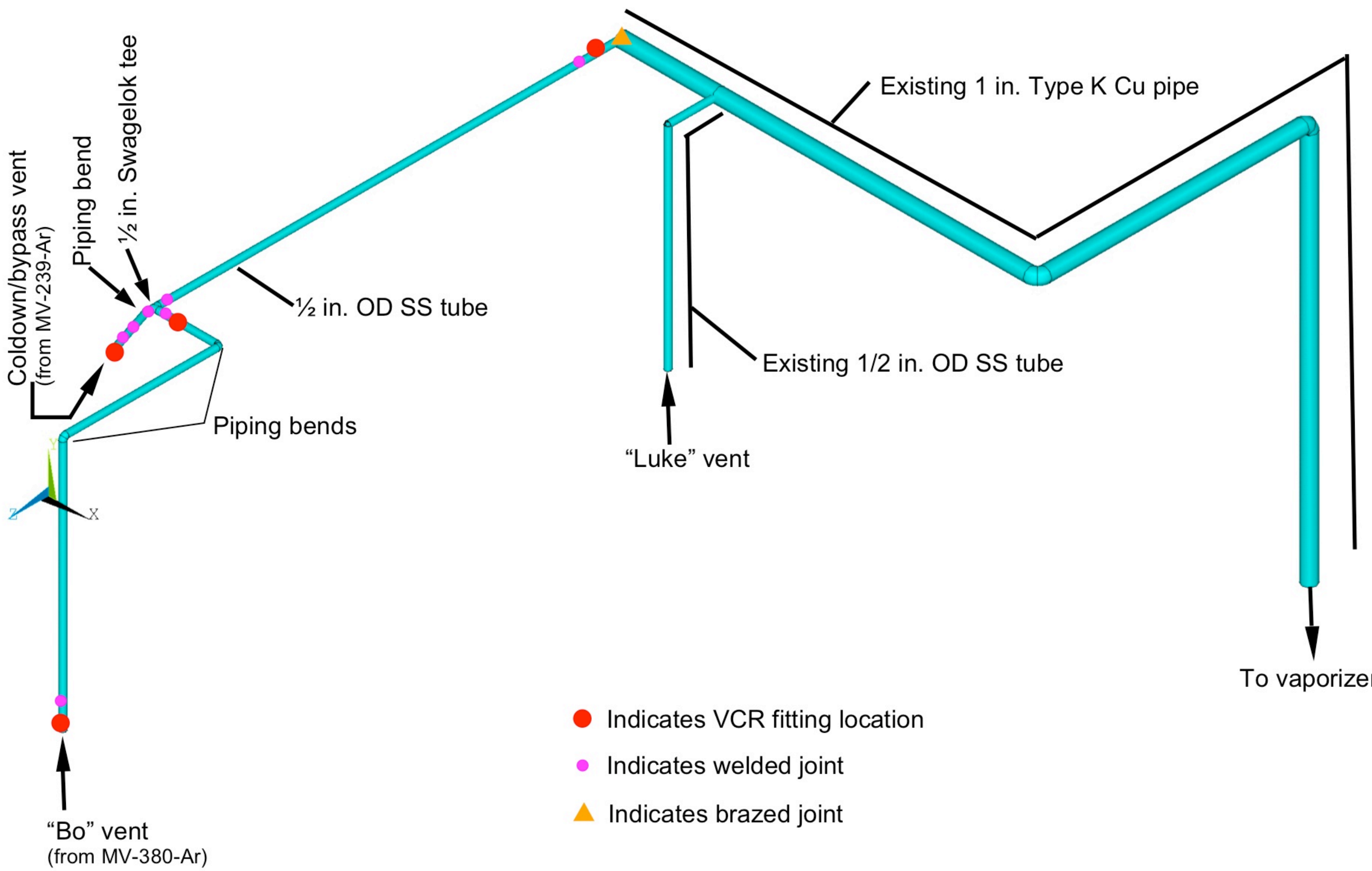


Figure 5.2: "Bo" cooldown/blowdown vent piping

The minimum thickness of the pipes is evaluated using the procedures in 304.1.2(a) of ASME B31.3. The minimum tube thickness for seamless or longitudinally welded piping for t<D/6 is given by:

$$t = \frac{PD}{2(SEW + PY)}$$

where: t = wall thickness, (manufacturers minimum value is used)

P = internal design pressure

D = outside diameter (manufacturers nominal value is used)

S = allowable stress from table A-1

E = quality factor from table A-1A or A-1B = 0.8 (worst case)

W = weld joint strength reduction factor = 1

Y = coefficient from Table 304.1.1 = 0.4

Table 5.1 summarizes the results of the wall thickness calculation.

Table 5.1. Cryogenic piping parameters

Pipe / Tube	*P* (psid)	*D* (in)	*S* (psi)	*E*	*t* req'd (in)	*t* mfg min (in)	MAWP (psid)
LAr supply line (vacuum jacketed)	400[a]	0.500	16,700	0.8	0.00740	0.0315	1772
"Bo" relief valve supply piping	35[b]	1.900	16,700	0.8	0.00249	0.0954	1397
"Bo" relief valve discharge piping	< 1[c]	3	16,700	0.8	0.0001	0.0585	529
"Bo" cooldown/blowdown vent piping	<< 350[d]	0.500	16,700	0.8	0.0065	0.0315	1772

(a) Pressure limited by trapped volume relief valve (PSV-250-Ar).

(b) Pressure limited by cryostat ASME relief valve (PSV-377-Ar).

(c) Relief valve calculations estimate vent pressure drop as less than 1 psi (http://lartpc-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=265, Section 4.1a).

(d) Supply LAr dewer reliefs are set at 350 psig. The pressure in the cooldown/blowdown vent pipe during system cooldown (when the crysotat is bypassed) will be much less than 350 psig because 98% of the flow resistance is upstream of the vent pipe. The resistance coefficient for the supply piping up to the cooldown/blowdown vent piping is 340.9 while the resistance coefficient for the vent piping is only 4.3 (all piping converted to a common reference diameter).

In the above four cases the manufacturer's minimum wall thickness of the piping is greater than the minimum thickness required by ASME B31.3.

The "unlisted components" installed in the "Bo" cryostat piping system as defined in B31.3 Section 304.7.2 are shown in Table 5.2.

Table 5.2. Unlisted piping components.

Component	*Source*	*Pressure rating [psi]*	*System Design Pressure (psid)*	*Comment*
Union Tee, 0.50 in OD x 0.049 wall, 316L S.S.	Swagelok, 316L-8TB7-3	3,700[a]	400	----
Union Tee	Swagelok, SS-8-VCR-T	4,300 [a]	400	----
Reducing Union, 0.50 in. OD x 0.049 wall, 316L S.S.	Swagelok, 316L-8TB7-6-6	3,300[a]	400	----
VCR gland	Swagelok, SS-8-VCR-3	3,000[a]	400	304.7.2(a) Extensive service experience[c]
VCR body	Swagelok, SS-8-VCR-4	3,000[a]	400	304.7.2(a) Extensive service experience[c]
Bellows Sealed Valve	Swagelok, SS-8BG-V47	1,000	400	304.7.2(a) Extensive service experience[c]
Bellows Sealed Valve	Swagelok, SS-8BG-TW	1,000	400	304.7.2(a) Extensive service experience[c]
Conflat flange, 2 ¾ in.	Lesker	vacuum[b]	35	304.7.2(a) Extensive service experience[c]
Reducing Union	FNAL	See Figure 5.1 and 5.3 and associated discussion.		

(a) Swagelok literature states that the fitting pressure ratings are based on an allowable stress value of 20,000 psi in accordance with B31.3 (calculated at room temperature).

(b) During the pressure test of the TPC signal feed thru flange (section 3.5j of the system cryogenic safety report - http://lartpc-docdb.fnal.gov:8080/cgi-bin/ShowDocument?docid=265), a 2 ¾ in. conflat flange was part of the test setup. This test pressurized the 2 ¾ in. conflat to 400 psig without leakage. Thus the conflat was proof tested to > 3x the maximum operating pressure it will see per 304.7.2(c).

(c) These components have performed satisfactorily during several transfer of liquid argon to "Luke."

The piping bends are analyzed based on 304.2.1 of the Code. The minimum required thickness is given by:

$$t = \frac{PD}{2((SEW / I) + PY)}$$

where: t = wall thickness

P = internal design pressure, 400 psid

D = outside diameter, 0.50 in.

S = allowable stress from table A-1, 16,700 psi for 304 S.S.

E = quality factor from table A-1A or A-1B = 0.8 (worst case)

W = weld joint strength reduction factor = 1

Y = coefficient from Table 304.1.1 = 0.4

I = factor for location in pipe bend: intrados, extrados and centerline

The following equations are used to determine I at the three locations:

at the intrados: $$I = \frac{4(R_1 / D) - 1}{4(R_1 / D) - 2}$$

at the extrados: $$I = \frac{4(R_1 / D) + 1}{4(R_1 / D) + 2}$$

at the centerline: $I = 1.0$

R_1 = bend radius of the tubing, 5.0 in. and 3.0 in.

The results are as follows:

t(in) for 5 in. radius: at intrados = 0.00760; extrados = 0.00722; centerline = 0.00740 (same as straight tube).

t(in) for 3 in. radius: at intrados = 0.00773; extrados = 0.00712; centerline = 0.00740 (same as straight tube).

The bent tubing has a minimum wall thickness of 0.0315 inches so this requirement is satisfied.

The transition between the ½ inch SS 316L tee and the 3/8 in. OD Cu tube was fabricated from a Swagelok VCR tee (SS-8-VCR-T) as shown in Figure 5.3. Two sides of the tee are used to make up VCR joints that feed “Luke” and “Bo.” The third side of the tee has the VCR threads cut off and has a copper line brazed into it. Because the inside diameter of the tee is larger than the 3/8 in Cu tube OD, a Cu spacer was machined to create a tight fit for brazing. The joint was brazed by Cary Kendziora using XUPER 1020 XFC silver brazing alloy which has a tensile strength of 85 ksi (data sheet included in the appendix).

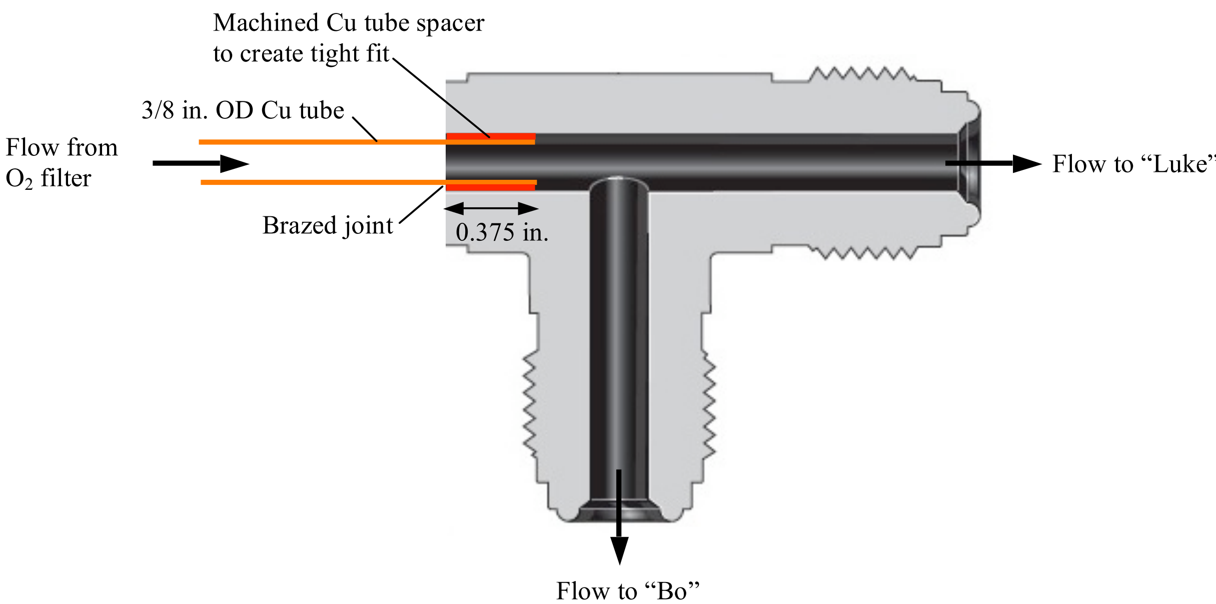


Figure 5.3: Brazed joint details

The flexibility of the LAr supply piping was analyzed using ANSYS. The model boundary conditions and results are summarized in Figures 5.4 and 5.5.

The thermal shrinkage was taken to be 290 x 10^{-5} $\Delta L/L$ for 304 Stainless and 314 x 10^{-5} $\Delta L/L$ for Cu tube. The modulus of elasticity of 304 Stainless was input as 2.07E11 Pa along with a Poisson’s Ratio of 0.28. The modulus of elasticity of Cu was input as 1.207E11 Pa along with a Poisson’s Ratio of 0.35. The model also considers the density of the contained fluid, which was input as 1400 kg/m^3 for argon.

The model is comprised of ANSYS PIPE 16 (straight), PIPE 17 (tee), and PIPE 18 (elbow) elements in which ANSYS calculates flexibility and stress intensification per B31.1. The stress intensification factors for B31.3 are the same as for B31.1.

The model contour plot shows a peak Von Mises stress of 12,154 psi where the ½ inch OD stainless steel tube is attached to the vent vacuum jacket.

Per B31.3 Appendix P, the operating stress is computed using equation (P17a)

$$S_o = \sqrt{\left(|S_a| + S_b\right)^2 + 4S_t^2}$$

where the axial (S_a), bending (S_b), and torsional (S_t) stresses are combined and compared to the allowable stress S_{oA} in para. P302.3.5(d) where

$S_{oA} = 1.25 f\left(S_c + S_h\right)$. S_c is the basic allowable stress at the minimum metal temperature expected during the displacement cycle under analysis and S_h is the basic allowable stress at the maximum metal temperature expected during the displacement cycle under analysis. Both S_c and S_h were taken to be 16,700 psi. The stress reduction factor f was taken to be 1.0 because this system will see less than 1,000 cycles in its lifetime.

$$S_{oA} = 1.25 \times 1.0 \times \left(16{,}700 + 16{,}700\right) = 41{,}750\, psi$$

A macro (available in the appendix) was used to retrieve S_a, S_b, and S_t from ANSYS and then compute the combined stress. The peak operating stress for this model was found to be 6,032 psi for the cold case (thermal shrinkage + 400 psid) and 1,163 for the warm case (400 psid loading only). Thus the operating stress range is only a few thousand psi and does not exceed the allowable operating stress limit.

These stresses are below the 16,700 psi limit for the 304 SS tube or the 6,000 psi limit for copper tube.

Figure 5.5 shows the results from a FEA model of the LAr vent piping that connects "Bo" and "Luke" to the LAr vaporizer. The model considers the stress that results from the shrinkage from 300 K to 80 K (no internal pressure). The material properties are the same as those used in the LAr supply piping flexibility analysis.

The model shows a peak Von Mises stress of 3,582 psi where the ½ inch OD stainless steel vent tube connects to Luke. Equation P17a computes a peak stress of 3,433 psi. Thus the stress in the venting piping is far below the basic allowables for both the stainless steel and copper piping.

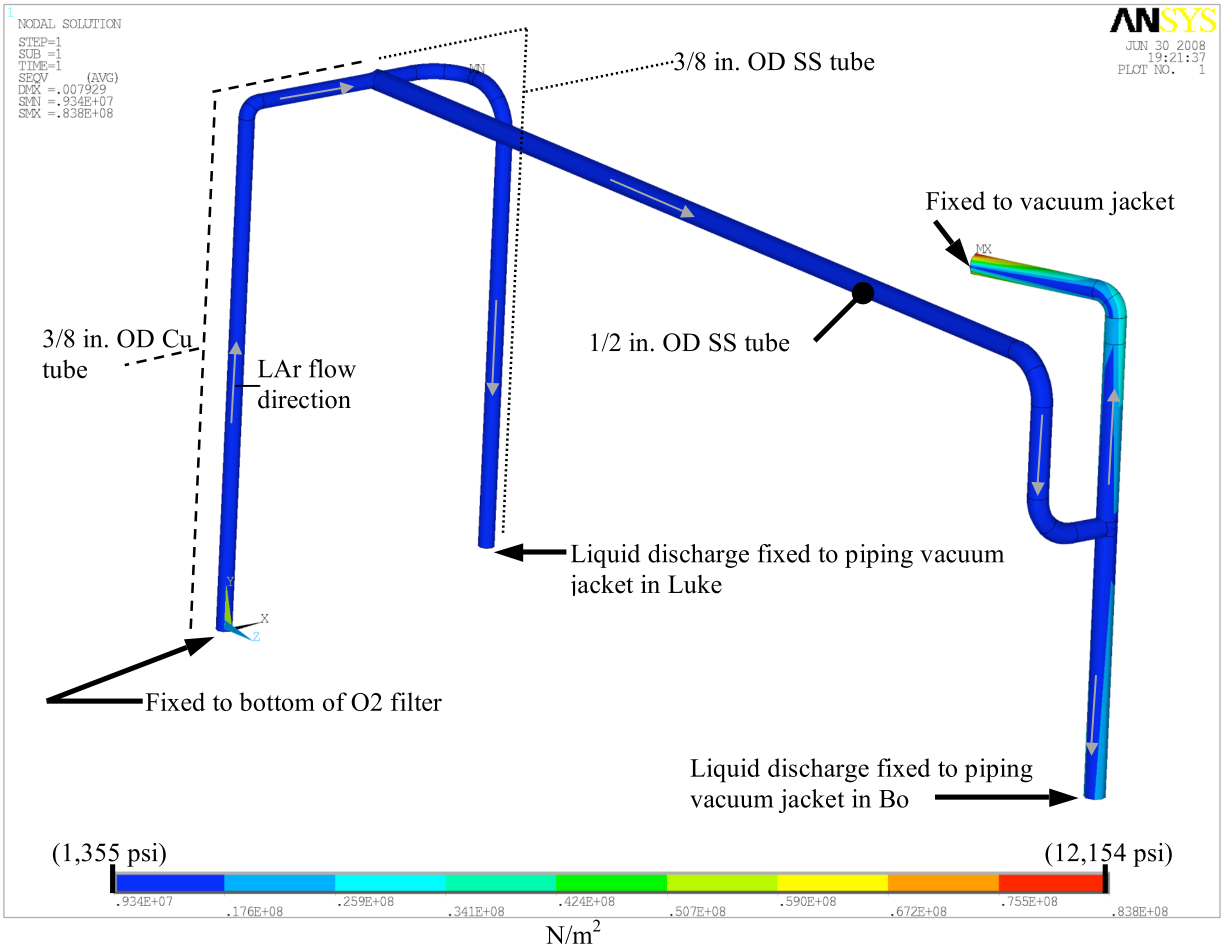


Figure 5.4: LAr supply piping Von Mises Stresses due to cooldown shrinkage and internal 400 psid pressure.

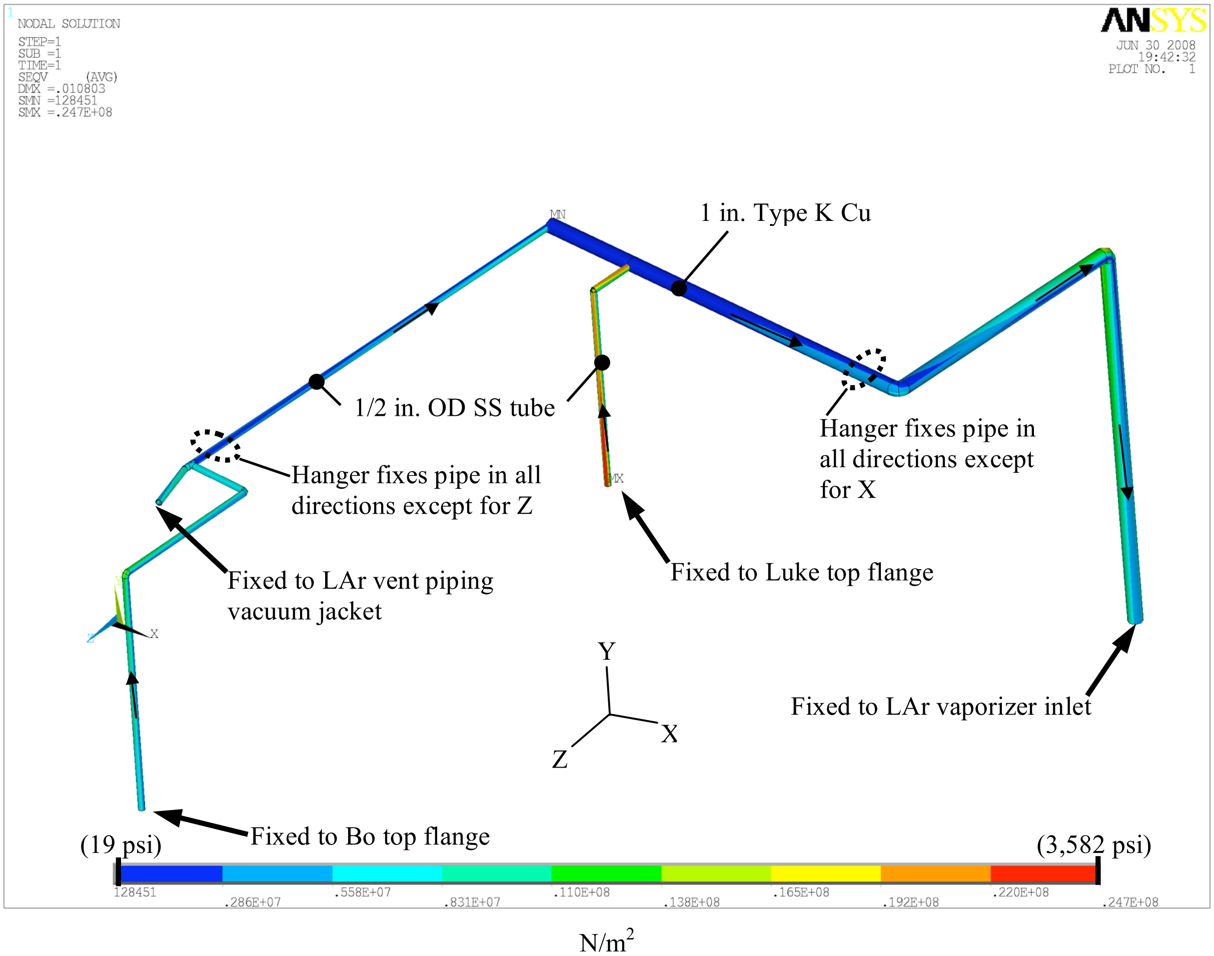


Figure 5.5: LAr vent piping Von Mises Stresses due to cooldown shrinkage.

6.0 Pressure relief system

The supply piping is relieved by an existing trapped volume relief PSV-250-Ar. The vent piping supplies the two cryostat relief valves, PSV-377-Ar and PSV-378-Ar.

Table 6.1: "Bo" LArTPC Cryostat piping relief settings.		
Circuit	*Design pressure*	*Relief setting*
"Bo" LAr supply line (vacuum jacketed)	400 psid	385 psig
"Bo" relief valve supply piping	35 psig	35 psig & 10 psig

7.0 Welding and inspection

According to B31.3 Section 341, all piping in Normal Fluid Service shall be examined. Normally radiographic examination of at least 5% of the welds is required but in certain cases the use of radiographic examination is difficult or all together impossible. This is the case here where assembly techniques prevent access to specific welds for radiography. The B31.3 piping code allows the use of in-process examination in lieu of radiography on a weld-for-weld basis for these cases. The ½ inch LAr supply tubing was welded by Dan Watkins. In-process inspection was carried out by Cary Kendziora on three of these welds. There are 15 welds in the LAr supply piping, thus the 5% inspection requirement is achieved. Dan Watkins also welded the ½ inch tube vent line attached to "Bo."

The two elbows that feed vent gas to the relief valves on "Bo" were welded by Jim O'Neill and radiographed (results available in the appendix). Jim O'Neill also welded the 3 inch OD vent line for the ASME coded and operational relief valves attached to "Bo."

8.0 Pressure testing

The piping system will be pressure tested in accordance with Section 5034 of the Fermilab ES&H Manual and 345.5 of the Code. The test pressure is 110% of the design pressure. The test pressures will be as follows:

- LAr supply circuit: 440 psig (while the vacuum jacket is evacuated an monitored).
- “Bo” cryostat: 40 psig

9.0 Category D piping

The portion of piping that is associated with “Bo” and designed to operate at room temperature and a maximum pressure of 35 psig is classified as Category D piping. This section describes these piping components.

There is one miter joint in the system. It is shown in Figure 9.1.

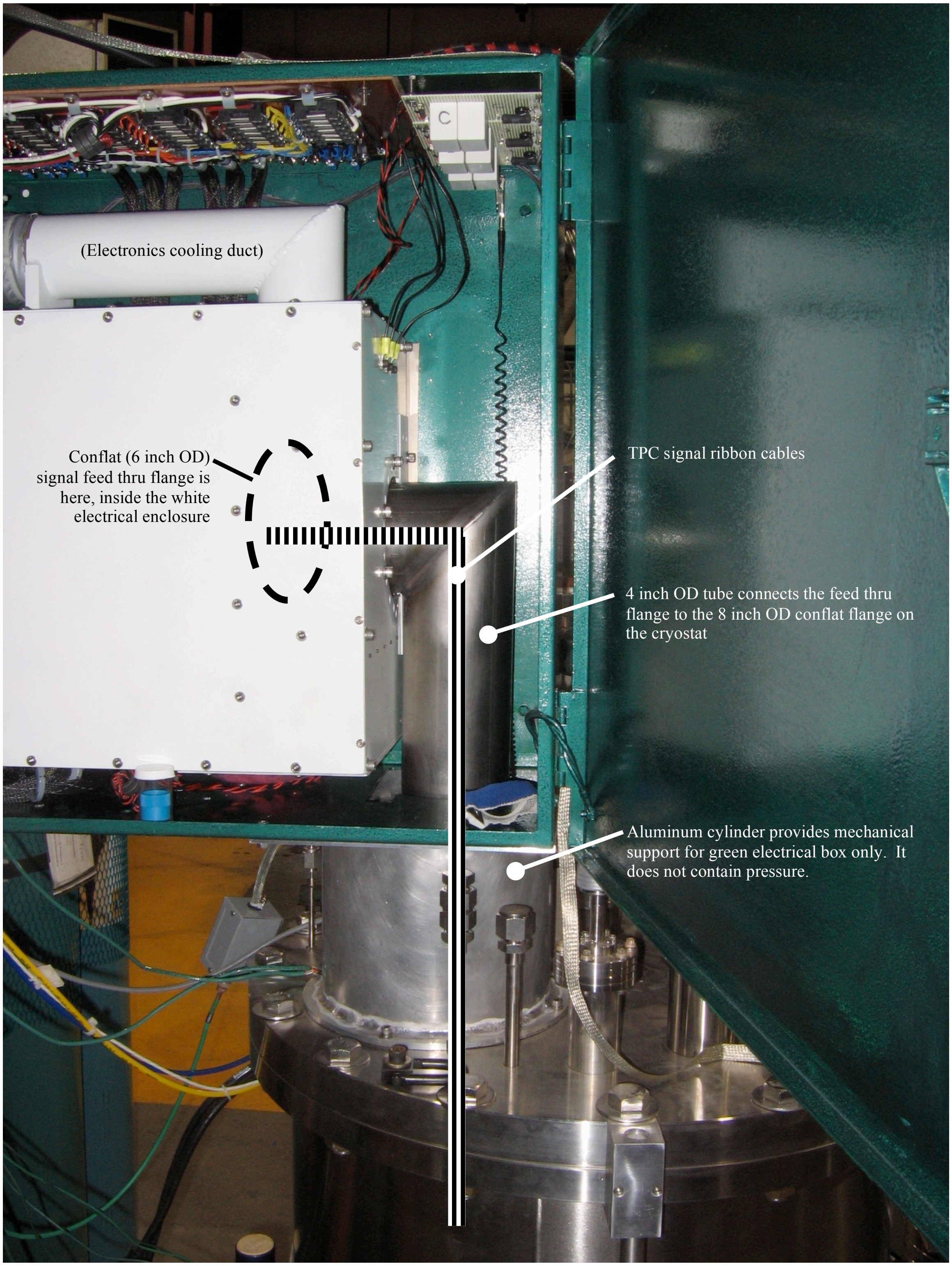


Figure 9.1: TPC signal feed thru miter joint.

The strength of the miter joint is analyzed per 304.2.3(2)(4c):

$$P_m = \frac{SEW(T-c)}{r_2}\left(\frac{T-c}{(T-c)+1.25\tan(\theta)\sqrt{r_2(T-c)}}\right)$$

S = 16,700 psi (Table A-1 for A 269 TP316L tube)

E = 0.8 (lowest value listed for A 269 spec. stainless steel tube)

W = 1.0 (per 302.3.5(e) for temperatures below 950 ^oF)

T = 0.0585 in. (Nominal wall thickness of 0.065 in. minus manufacturer's tolerance of 10%)

c = 0 (per 304.1.1(b) , the tubing has no thread or groove depth nor will corrosion or erosionn occur)

r_2 = 1.9675 in. (mean radius of pipe using nominal wall $\overline{T}$, 2 – 0.065/2)

θ = 45^o (angle of miter cut)

$$P_m = \frac{16{,}700\times0.8\times1.0(0.0585-0)}{1.9675}\left(\frac{0.0585-0}{(0.0585-0)+1.25\tan(45)\sqrt{1.9675(0.0585-0)}}\right) = 48.1\, psi$$

Thus the strength of the miter joint with respect to internal pressure is adequate for the MAWP of "Bo."

This section of piping will be evacuated such that it must be analyzed for external pressure. Para. 304.2.4 states that the wall thickness of curved and mitered segments of pipe subjected to external pressure maybe be determined as specified for straight pipe in para. 304.1.3. Para. 304.1.3 states that UG-28 thru UG-30 of the Section VIII Division 1 BPC code should be used to determine the external pressure rating.

First D_o / t is calculated where D_o is the pipe outside diameter of 4.0 inches and t is the wall thickness of 0.065 inches. D_o / t = 4.0 / 0.065 = 61.5.

Because Do / t is greater than 4, calculate L / D_o where L is the length of the cylinder which is 11 inches. $L / D_o = 11 / 4.0 = 2.75$. The length for the longest section of this diameter piping is used.

Because L / D_o is greater than 0.05 and less than 50, enter Figure G in ASME Section II Part D and locate the value for Factor A. With a $L / D_o = 2.75$ and $D_o / t = 61.5$, Factor A = 0.001.

From Figure HA-4 in Section II Part D, Factor B is 9,200 based on Factor A equal to 0.001 and the 100 ^oF modulus curve.

Because D_o / t is greater than 10, the maximum allowable external pressure is calculated using

$$P = \frac{4B}{3\frac{D_o}{t}} = \frac{4 \times 9{,}200}{3\frac{4.0}{0.065}} = 199\,psi.$$

The section of tubing that contains the mitered joint can handle the external pressure due to vacuum because 199 psi >> 15 psi.

The welds in this section of piping have been visually examined per 341.4.2.

The purge flow to and from FI-390-Ar is supplied thru ¼ in. OD polyurethane tubing which is rated for use from vacuum to 265 psi (McMaster part #5648K416). The supply of GAr to this section is limited to 35 psig by PSV-276-Ar.

The vacuum jacket that surrounds the “Bo” LAr supply line is comprised of 4 in. OD 316L tubing (0.065 inch wall thickness). This tubing is welded to “Marmon” flanges which were fabricated from MB-359521 which is entitled “Main Injector Vacuum System ϕ Quick Disconnect Flange.” Based on extensive, successful service experience, the “Marmon” flanges are qualified for this vacuum service. The longest length (11 ft.) of 4 in. OD tubing is analyzed with respect to external pressure.

First D_o / t is calculated where D_o is the pipe outside diameter of 4.0 inches and t is the wall thickness of 0.065 inches. $D_o / t = 4.0 / 0.065 = 61.5$.

Because Do / t is greater than 4, calculate L / D_o where L is the length of the cylinder which is 11 inches. $L / D_o = 11 \times 12 / 4.0 = 33$.

Because L / D_o is greater than 0.05 and less than 50, enter Figure G in ASME Section II Part D and locate the value for Factor A. With a $L / D_o = 33$ and $D_o / t = 61.5$, Factor A = 0.0003.

From Figure HA-4 in Section II Part D, Factor B is 4,100 based on Factor A equal to 0.0003 and the 100 ^{o}F modulus curve.

Because D_o / t is greater than 10, the maximum allowable external pressure is calculated using

$$P = \frac{4B}{3\frac{D_o}{t}} = \frac{4 \times 4{,}100}{3\frac{4.0}{0.065}} = 89\,psi.$$

Thus the longest section of vacuum jacket tubing (and any of the shorter similarly constructed sections) can handle the external pressure due to vacuum because 89 psi >> 15 psi.

The instrumentation port that provides access to the insulating vacuum of "Bo" is comprised of the components shown on the flow schematic and listed in the PI&D (such as PT-17-V) and three pieces of piping. These pieces are a Swagelock VCR tee (vacuum to 10,000 psig rating), a VCR to KF 25 adaptor (rated for vacuum), and a KF 25 cross (rated for vacuum).

The piping that connects the commercial turbo vacuum pump cart to the cryostat has a total length of 6 inches and consists of two 3 inch long sections of piping. The first section adapts from a 4 ½ inch OD conflat vacuum flange to a 6 inch OD conflat vacuum flange and these two flanges are joined by a SS 304L 2.5 inch OD tube with a 0.065 inch wall. A longer section of 2.5 inch OD tube with the 0.065 inch wall is shown to be adequate for 15 psid external pressure in the document entitled "ASME Calculations for the "Bo" cryostat top flange." The second short section of vacuum piping consists of a 3 inch long 4 inch OD / 0.065 inch thick wall SS 316L tube with 6 inch OD conflat flanges on either end. This tubing is qualified for the external pressure due to vacuum in the previous section that describes the vacuum jacket.

PI-363-Ar is connected using a SS 304L 3/8 inch OD tube with a 0.035 inch wall thickness. Using the equation in Section 5 of this document that relates wall thickness and pressure, this section of piping is rated for 2400 psig internal pressure based on the manufacturers minimum wall thickness which far exceeds the needed 35 psig rating. Its external pressure rating is calculated in the usual manner.

First D_o / t is calculated where D_o is the pipe outside diameter of 0.375 inches and t is the wall thickness of 0.035 inches. $D_o / t = 0.375 / 0.035 = 10.7$.

Because Do / t is greater than 4, calculate L / D_o where L is the length of the cylinder which is 12 inches. $L / D_o = 12 / 0.375 = 32$.

Because L / D_o is greater than 0.05 and less than 50, enter Figure G in ASME Section II Part D and locate the value for Factor A. With a $L / D_o = 32$ and $D_o / t = 10.7$, Factor A = 0.011.

From Figure HA-3 in Section II Part D, Factor B is 15,000 based on Factor A equal to 0.011 and the 100 ^{o}F modulus curve.

Because D_o / t is greater than 10, the maximum allowable external pressure is calculated using

$$P = \frac{4B}{3\frac{D_o}{t}} = \frac{4 \times 15{,}000}{3\frac{0.375}{0.035}} = 1{,}867\,psi.$$

Thus the section of tubing connecting the pressure gauge to the vapor space of “Bo” can handle the external pressure due to vacuum because 1,867 psi >> 15 psi.

PT-373-Ar is connected to a Swagelock VCR male gland (pressure rating vacuum – 4,300 psig) that is welded to a 2 ¾ inch conflat flange.

RD-376-Ar is welded to a 1.5 inch OD / 0.065 inch wall SS 304L tube. Using the equation in Section 5 of this document that relates wall thickness and pressure, this section of piping is rated for 1,076 psig internal pressure based on the manufacturers minimum wall thickness which far exceeds the needed 35 psig internal pressure rating.

Its external pressure rating is calculated in the usual manner.

First D_o / t is calculated where D_o is the pipe outside diameter of 1.500 inches and t is the wall thickness of 0.065 inches. $D_o / t = 1.500 / 0.065 = 23.1$.

Because Do / t is greater than 4, calculate L / D_o where L is the length of the cylinder which is 4.5 inches. $L / D_o = 4.5 / 1.500 = 3$.

Because L / D_o is greater than 0.05 and less than 50, enter Figure G in ASME Section II Part D and locate the value for Factor A. With a $L / D_o = 3$ and $D_o / t = 23.1$, Factor A = 0.0036.

From Figure HA-3 in Section II Part D, Factor B is 11,000 based on Factor A equal to 0.0036 and the 100 ^{o}F modulus curve.

Because D_o / t is greater than 10, the maximum allowable external pressure is calculated using

$$P = \frac{4B}{3\frac{D_o}{t}} = \frac{4 \times 11{,}000}{3\frac{1.500}{0.065}} = 636\,psi.$$

Thus the section of tubing connecting the rupture disk can handle the external pressure due to vacuum because 636 psi >> 15 psi.

PT-374-V is attached directly to a conflat flange.

10.0 Appendix

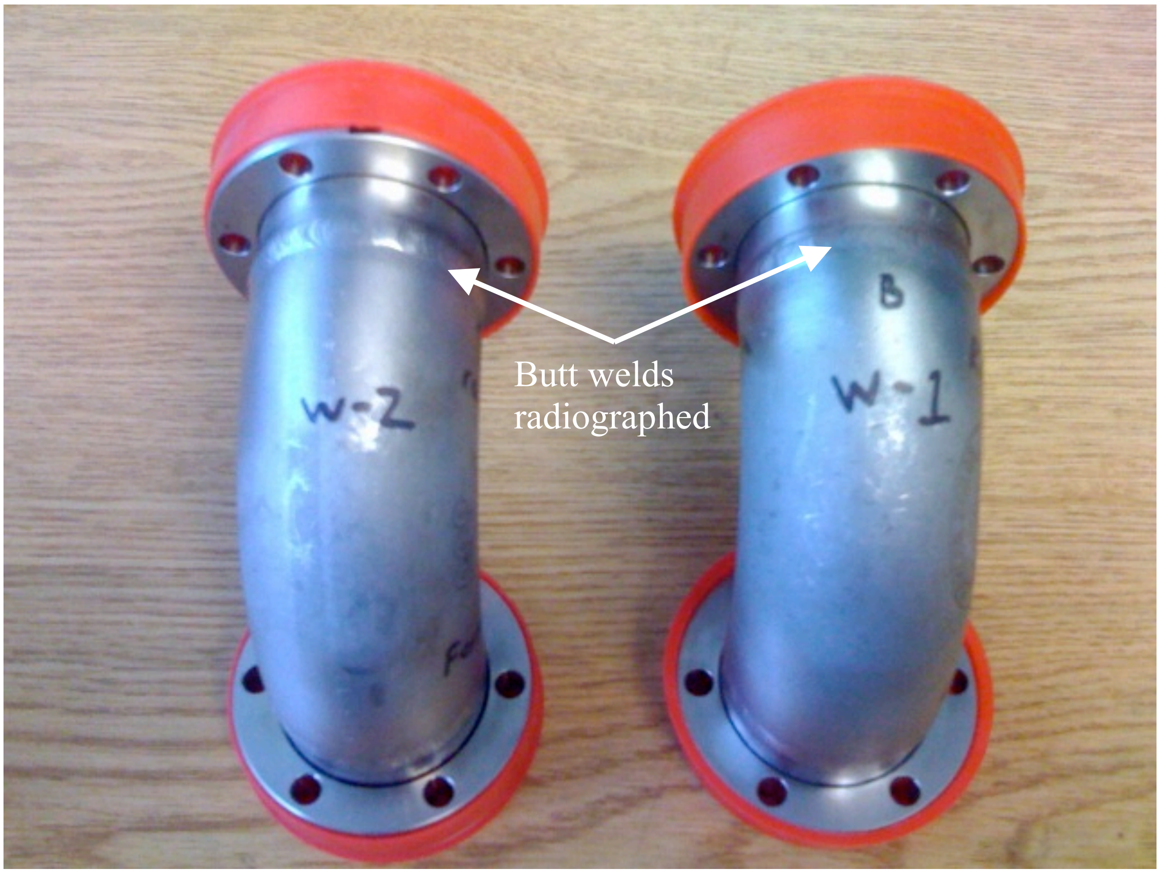


Figure A.1: "Bo" relief valve supply elbows sent out for radiography.

TEAM Industrial Services, Inc.

RADIOGRAPHIC INSPECTION REPORT (Gamma)

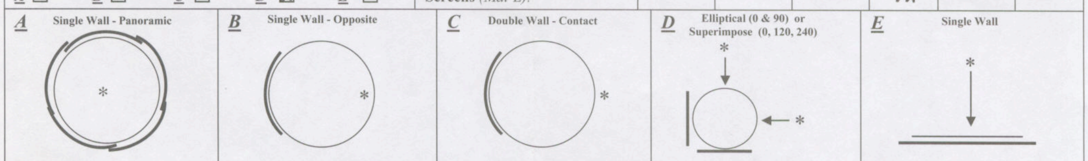
TEAM Industrial Services
3640 West 179TH Street
Hammond, IN. 46323
(219) 838-0505 Fax#:-8558

Form: 20.1 – 212, Rev 2

Customer: FERMILAB	Location: 3640 179th HAMMOND IND.	WO No.: 10388047
Specification: ASME SEC V	Acceptance Std: ASME B31.3	TEAM Procedure: RT. ASME. I

Radiation Source Type: IR-192 ☒ Co-60 ☐	Source Strength: 70 CI	Effective Focal Spot Size: .119"	Film to Source Distance (SFD): 24"	Exposure Time: 2 MIN
Pipe Diameter: 1½"	Plate Thickness: N/A	Weld Thickness: .109" +Reinf.	Joint Type: BUTT	Material Type: S/S
Penetrameter: (Type / Size) ASTM 12	Material Type: S/S	Penetrameter Location Source Side ☒ Film Side ☐	Shim Mat'l: S/S	Shim Thickness: .065"
Film Type: KODAK "T"	Film Size: 4½" X 10"	Film Emulsion #: 211 109	Film Exp.: 8/10	Film Technique Single ☒ Multiple ☐
Film Processing Manual ☒ Automatic ☐				

Exposure Arrangement: A ☐ B ☐ C ☐ D ☒ E ☐	Intensifying Screens (Mat'L): Pb	Front	.010"	Center	N/A	Back	.010"



EXPOSURE NO.	WELD NO.	VIEW	"UG"	Original or Repair	ACCEPT	REJECT	Porosity	Slag or Inclusion	Tungsten Inclusion	Incomplete Fusion	Inadequate Penetration	Crack	Root Concavity	Root Convexity	Undercut	Film Artifact	Remarks	Pnentrameter Density	Weld Density
	W-1	A	≤.02	O	✓													2.0 / 4.0	2.0 / 4.0
		B			✓														
		C			✓														
	W-2	A			✓														
		B			✓														
		C			✓														
	W-3	A				X				X									
		B				X				X									
		C			✓														

Inspector: PRINT CHRISTOPHER B. WOOD	SIGNATURE Christopher B. Wood	Level: II	Date: 6/18/08

Figure A.2: Radiography results. Weld W-3 is a weld that is part of a different piping system that is not associated with "Bo."

post.dat

```
/post1

/sys, del results.res

esel,s,ename,,16

etab,sa,smisc,13
etab,sb,nmisc,90
etab,st,smisc,14

esel,s,ename,,17

etab,sa,smisc,37
etab,sb,nmisc,268
etab,st,smisc,38

esel,s,ename,,18

etab,sa,smisc,13
etab,sb,nmisc,91
etab,st,smisc,14

allsel

*get,ecnt,elem,,count  ! number of elements selected
*do,qq,1,ecnt           ! loop through the elements
/gopr
*get,e1,elem,,num,min   ! get starting element, lowest number

*get,ssa,elem,e1,etab,sa
*get,ssb,elem,e1,etab,sb
*get,sst,elem,e1,etab,st

/out,results,res,,append
res_%e1%=sqrt((abs(ssa)+ssb)**2+4*sst**2)
/out

esel,u,elem,,e1
*enddo
```

Page 1

Figure A-3: ANSYS macro used to compute operating stress.

Fermilab

WELDER QUALIFICATION TEST RECORD

Welder's Name Dan Watkins Ident. No. 25 Date 3-9-84
Welding Process(es) GTAW Type Manual
Test in Accordance with WPS No. 155001
Material Spec. Spec/Grade No. SA 213T304 to Spec/Grade SA 213T304
P No. 8 to P No. 8 Thick. .277 Dia. 6"
Filler Metal Spec. No. SFA 5.9 Class. No. ER308 F No. 6
Backing None
Position 6G Weld Progression Upward
Gas Type Argon Composition 100%
Electrical Characteristics: Current DC Polarity Straight
Other Qualifies up to .554" Thickness

FOR INFORMATION ONLY

Filler Metal Diameter and Trade Name Techalloy 1/16"
Submerged Arc Flux Trade Name N/A
Gas Metal Arc Welding Shield Gas Trade Name N/A

GUIDED BEND TEST RESULTS

Specimen No.	Type	Figure No.	Results
1	Face	QW 462.3a	Acceptable
2	Root	QW 462.3a	Acceptable
3	Face	QW 462.3a	Acceptable
4	Root	QW 462.3a	Acceptable

RADIOGRAPHIC TEST RESULTS
(FOR ALTERNATIVE QUALIFICATION BY RADIOGRAPHY)

Radiographic Results N/A
Test Conducted by IFR Engineering Test No. 008-15

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordace with the requirements of Section IX of the ASME Code.

By: James Provoto

Date: 4/4/84

Figure A-4: Dan Watkin's welding qualification for stainless steel.

Fermilab

WELDER QUALIFICATION TEST RECORD

Welder's Name James M. O'Neal Ident. No. 1 Date 9-16-82
Welding Process(es) GTAW Type Manual
Test in Accordance with WPS No. 155001
Material Spec. Spec/Grade No. SA 213 304 to Spec/Grade SA 213 304
P No. 8 to P No. 8 Thick. .277 Dia. 6"
Filler Metal Spec. No. SFA 5.9 Class. No. ER 308 F No. 6
Backing No
Position 6G Weld Progression Up
Gas Type Argon Composition
Electrical Characteristics: Current DC Polarity Straight
Other Thickness Range Qualified: 0.062 - 0.554

FOR INFORMATION ONLY

Filler Metal Diameter and Trade Name 1/16, 3/32 Sandvick
Submerged Arc Flux Trade Name n/a
Gas Metal Arc Welding Shield Gas Trade Name n/a

GUIDED BEND TEST RESULTS

Specimen No.	Type	Figure No.	Results
1	Face	QW 462.3a	Acceptable
2	Root	QW 462.3a	Acceptable
3	Face	QW 462.3a	Acceptable
4	Root	QW 462.3a	Acceptable

RADIOGRAPHIC TEST RESULTS
(FOR ALTERNATIVE QUALIFICATION BY RADIOGRAPHY)

Radiographic Results n/a
Test Conducted by IFR Engineering Test No. 47445

We certify that the statements in this record are correct and that the test welds were prepared, welded and tested in accordace with the requirements of Section IX of the ASME Code.

By: [illegible]
Date: 9/29/82

Figure A-5: Jame's O'Neal's welding qualifications for stainless steel.

Excellent Fluidity for Good Wetting

Xuper® 1020® XFC® Silver Brazing Alloy Coated With a Super-Active Flux for use on a Wide Range of Metals

•Unique elastic flux coating is flexible and will not chip or peel

•Best combination of strength, ductility, and flowability with control

•3/64" diameter for delicate work

•Works on ferrous and non-ferrous metals; joins dissimilar metals.

•Thin-flowing, yet bridges poor-fit gaps

•No separate fluxing needed in most cases

•Cadmium-free deposits

•Active flux prevents surface oxides from forming

•Low application temperature

•High tensile strength

•Excellent for maintenance and production joining

•Easy to use--all skill levels can achieve excellent results

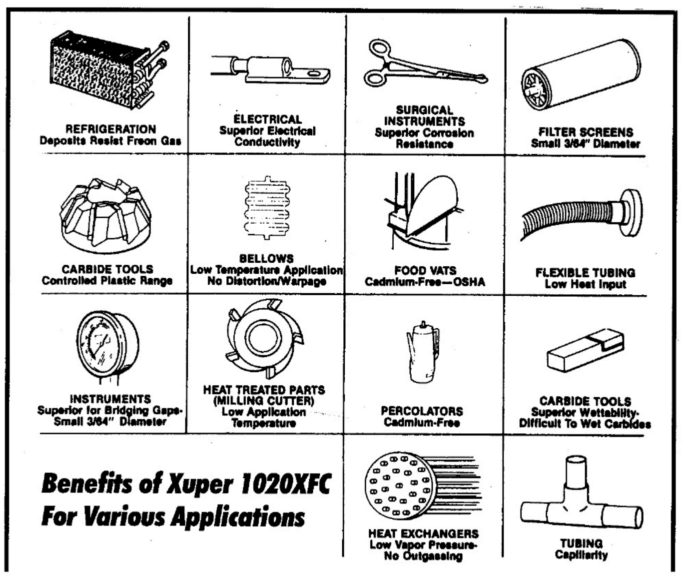


Figure A-6: Brazing alloy used to join stainless steel and copper parts.

Xuper®1020® XFC® Technical Data

Description: Flux-coated silver type alloy with double-action cleansing to prevent oxidation. ElasTec™ flux coating prevents chipping, permits bending to suit all positions and is highly super-active. Unusually fluid, with excellent wetting action on a wide range of ferrous and non-ferrous metals. *Not recommended for cast iron or white metals.*

Joints are clean, dense and free of inclusions and porosity. Good electrical conductivity. Ideal for food and beverage applications, since it is cadmium-free and corrosion resistant.

Application Method: Oxyacetylene torch. Can be applied with propane, city gas, natural gas or blow torch when small, thin-gauge metal sections are joined.

Deposit Characteristics: High strength, dense, ductile and impact-resistant. Can be plated. Silver-white in color, thus a good color match for stainless steels and nickel alloys

Application Procedure: Parts should be reasonably clean and free of grease or oil. Remove burrs and jagged edges. Use jigs or fixtures, or Eutectic® Form-A-Jig™ compound to maintain alignment.

Heat broadly along joint line with a carburizing oxyacetylene flame. Touch rod to joint from time to time until the flux begins to melt off. Continue heating until flux liquefies. At that point feed the alloy into the joint, keeping the flame cone a least one inch away. Continue melting the rod until a continuous fillet is achieved. Rotate rod between fingers during feeding to prevent "melt-back" of flux.

For long lap joints, complex sections or contaminated parts use supplemental Xupersil™ Paste Flux as recommended. Allow deposit to solidify, then quench in water and wash away residue.

Bonding Temperature: 1050° F

Melting Range: 1145° - 1205° F

Preheat: 500 - 600° F

Tensile strength: 85,000 psi

Sizes: 3/32", 1/16", 3/64" diameters; 18" length

Identification: Pink coating

Typical Hardness: Rb 75

Item Code: 3/32--BO12113

Castolin Eutectic®
Eutectic Castolin

Eutectic Corporation
9600-H Southern Pine Blvd. Charlotte,NC 28273 USA
East/Midwest 800-323-4845
West 800-662-0051

Eutectic Canada Inc.
4200 route Trans Canadienne, Pointe Claire,Quebec H9R 1B6
Canada 514-695-7500

Figure A-6 continued.

PPD Vacuum and Instrumentation Group
In-Process Weld Inspection Form

(as per In-Process Weld Inspection Guidelines, AD Cryogenics, Nov 3, 2006)

Date__April 15_______ Project: ___LAr Transfer Line___
Pipe Section: _Between Luke and Bo__ Weld Number:___5______
Weld location: Vacuum insulated LAr transfer line______________
Welder:____Dan Watkins__ Inspector: _____C.Kendziora_____

Before Welding:
Type of weld: (butt)__X____ (other)_____
(1) Pipe #1 Size, Schedule and material: _______1/2" OD___.035" wall____
(2) Pipe #2 Size, Schedule and material: _______1/2" OD___.035" wall____

(1) Joint Preparation and Cleanliness
Joint Preparation and Cleanliness acceptable? ___Yes_______

(2) Welding Machine
(a) Remote foot pedal? ___Yes__
(b) DC straight machine? __Yes___

(3) Joint Fit-up, and Internal Alignment.
(a) Internal alignment acceptable? ____Yes_________
(b) Joint Clearance acceptable? _____Yes_______
(c) End Preparation acceptable? _____Yes______

(4) Filler Rod
(a) AWS A5.9 stainless steel filler rod? ____Yes______
(b) Filler rod: Class ___A5.9_______ Diameter__0.035_______

(5) Purge Gas.
(a) type of purge gas : _____Argon_______
(b) time length of purge: ____10min_______ purge flow rate:____10 SCFH___
(b) (if done) O2 reading: __________O2 Monitor manf/model : _______

(6) Inspection After Root Pass
(a) No visible cracks. ____None____
(b) No suck holes, which are small holes in middle of weld. _None______
(c) No porosity or obvious imperfections. ____None__
(d) Filler material fused along edges of weld . _Yes_____

(8) Repeat inspection after every pass: _____________

(9) Final Inspection: _______Yes________

Figure A-7: In process weld inspection forms.

PPD Vacuum and Instrumentation Group
In-Process Weld Inspection Form

(as per In-Process Weld Inspection Guidelines, AD Cryogenics, Nov 3, 2006)

Date__April 15_______ Project: ___LAr Transfer Line___
Pipe Section: _Between Luke and Bo__ Weld Number:___7______
Weld location: Vacuum insulated LAr transfer line_______________
Welder:____Dan Watkins__ Inspector: _____C.Kendziora_____

Before Welding:

Type of weld: (butt)__X____ (other)_____
(1) Pipe #1 Size, Schedule and material: _______1/2" OD___.035" wall____
(2) Pipe #2 Size, Schedule and material: _______1/2" OD___.035" wall____

(1) Joint Preparation and Cleanliness

Joint Preparation and Cleanliness acceptable? ___Yes_______

(2) Welding Machine

(a) Remote foot pedal? ___Yes__
(b) DC straight machine? __Yes___

(3) Joint Fit-up, and Internal Alignment.

(a) Internal alignment acceptable? ____Yes_________
(b) Joint Clearance acceptable? _____Yes_______
(c) End Preparation acceptable? _____Yes______

(4) Filler Rod

(a) AWS A5.9 stainless steel filler rod? ____Yes______
(b) Filler rod: Class ___A5.9_______ Diameter__0.035_______

(5) Purge Gas.

(a) type of purge gas : _____Argon_______
(b) time length of purge: ____10min_______ purge flow rate:__10 SCFH___
(b) (if done) O2 reading: __________O2 Monitor manf/model : _______

(6) Inspection After Root Pass

(a) No visible cracks. ____None____
(b) No suck holes, which are small holes in middle of weld. _None______
(c) No porosity or obvious imperfections. ____None__
(d) Filler material fused along edges of weld . _Yes_____

(8) Repeat inspection after every pass: _____________

(9) Final Inspection: _______Yes________

Figure A-7 continued.

PPD Vacuum and Instrumentation Group
In-Process Weld Inspection Form
(as per In-Process Weld Inspection Guidelines, AD Cryogenics, Nov 3, 2006)

Date 6/30/08 **Project:** LAR: VENT LINE
Pipe Section: VENT LINE **Weld Number:** V101
Weld location: TEE ABOVE VALVE
Welder: DAN WATKINS **Inspector:** Gary Kendziora

Before Welding:
Type of weld: (butt) ✓ (other)________
(1) Pipe #1 Size, Schedule and material: TUBING 1/2" OD .035 WALL
(2) Pipe #2 Size, Schedule and material: ________

(1) Joint Preparation and Cleanliness
Joint Preparation and Cleanliness acceptable? Yes

(2) Welding Machine
(a) Remote foot pedal? ✓
(b) DC straight machine? ✓

(3) Joint Fit-up, and Internal Alignment.
(a) Internal alignment acceptable? Yes
(b) Joint Clearance acceptable? Yes
(c) End Preparation acceptable? Yes

(4) Filler Rod
(a) AWS A5.9 stainless steel filler rod? ✓
(b) Filler rod: Class ER 308 Diameter .035

(5) Purge Gas.
(a) type of purge gas : ARGON
(b) time length of purge: 60 SEC. purge flow rate: 5 SCFH
SCFH ✓
(b) (if done) O2 reading: ________ O2 Monitor manf/model : ________

(6) Inspection After Root Pass
(a) No visible cracks. ✓
(b) No suck holes, which are small holes in middle of weld. ✓
(c) No porosity or obvious imperfections. ✓
(d) Filler material fused along edges of weld . ✓

(8) Repeat inspection after every pass: ________

(9) Final Inspection: Looked Good

Figure A-7 continued.